

High p_T Direct Photon-Hadron Correlations Using the PHENIX Detector

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Abstract. Jet tomography, the study of differential energy loss of hard scattered partons to infer the density profile of the medium, is greatly improved by precise knowledge of the initial energy of the hard probe. As photons are not strongly interacting, the momentum of the recoil jet from a direct photon trigger is balanced, to a good approximation, by the momentum of the photon. The energy loss of the away-side jet may be viewed as an effective modification of the fragmentation function. Direct photon-hadron correlations in $A+A$ collisions should be sensitive to modified jet fragmentation as well as to medium response effects. Complementary measurements from $p+p$ collisions are necessary to benchmark jet fragmentation expectations at $\sqrt{s} = 200\text{GeV}$ as well as to constrain perturbative calculations in the $\gamma + jet$ channel. Here we present new results from $p+p$ and $Au+Au$ collisions which use a statistical method to subtract the background from decay photons.

1. Introduction

$\gamma + jet$ events have long been considered to be a useful probe of partonic energy loss in nuclear collisions.[1] To first approximation $\gamma + jet$ is well represented by the LO QCD Compton scattering process $q + g \rightarrow q + \gamma$. Due to the dominance of this process the $\gamma + jet$ cross-section should provide a constraint on the gluon distribution function in elementary particle collisions.[3] In central nuclear collisions at RHIC energies the hard-scattered parton may lose energy as it traverses the nuclear medium but the photon will not. In principle, jet energy loss measurements should constrain the parameter \hat{q} which controls the strength of the energy loss. Although di-jet events occur at a much higher rate than $\gamma + jet$ events, the initial energy of the outgoing partons is hard to determine, complicating their interpretation. In the case of prompt photons arising from the Compton process the initial energy of the jet may be estimated by measuring the energy of the photon.

Two particle correlation measurements have a history in high energy physics pre-dating the advent of sophisticated jet reconstruction algorithms. These techniques have proven useful with regard to the high multiplicity RHIC data where the application of these algorithms is problematic. Single and di-hadron measurements have shown the strong suppression of high p_T hadron yields [4] and the disappearance of the away-side jet at high p_T [5] [6]. However these observables may be dominated by jet production near the surface of the collision zone [7]. Direct photon-hadron correlations should not suffer from the same geometrical bias. Insofar as the jet kinematics may be considered fixed by the photon energy, particle production on the away-side should represent a path length averaged energy loss. Departure from vacuum fragmentation

expectations for away-side hadron distributions may be viewed as the combined effect of energy loss and the response of the medium to the deposited energy.

As a matter of nomenclature we consider direct photons to be all photons not from hadron decay. Hence we include photons from jet fragmentation, which are allowed at NLO. Typically the latter are removed by isolation requirements, but such cuts are difficult to apply in heavy-ion collisions. Baseline measurements for fragmentation photons are necessary as the parton \rightarrow photon fragmentation functions are not well constrained. Although the energy loss mechanism should suppress production of these photons in central $Au + Au$ collisions, additional photon bremsstrahlung may be induced by the presence of the strong color fields, which would be an interesting energy loss observable in its own right. [9]

2. Analysis Technique and Results

The main challenge experimentally is to subtract the large background associated with photons from meson decay. In $p + p$ collisions direct photons are sub-dominant to decay photons until approximately 10GeV . In central $Au + Au$ collisions direct photons gain greater significance relative to the decay photon background due to the suppression of high p_T jet-associated hadrons.

The decay photon associated yield is deduced from the measure π^0 -h associated yield via a Monte Carlo procedure which takes in to account the decay kinematics and detector effects.

One may then perform a statistical subtraction of per-trigger yields using

$$Y_{direct} = \frac{1}{R_\gamma - 1} \cdot (R_\gamma Y_{inclusive} - Y_{decay}). \quad (1)$$

where Y is defined as dN_{pairs}/N_{trig} yield and R_γ is the ratio of the number of inclusive photons to the number of decay photons. R_γ has been measured in $Au + Au$ collisions and may be derived from the measured direct photon and π^0 spectra in $p + p$.

Figures 1 and 2 show per-trigger yields of charged hadrons for π^0 and direct photon triggers from the Run 6 $p + p$ data set for the near and away-side, respectively. The systematic error is dominated by the uncertainty in the R_γ and the contribution from heavy meson decay. The measurement extends over a large kinematic range, from $5 < p_{T,\gamma} < 15$. On the near-side the data don't allow large particle production from fragmentation. This is consistent with prompt photon production, although current uncertainties leave room for some contribution from near-side fragmentation. On the away-side the per-trigger yields for direct photon look similar to π^0 yields. At fixed trigger p_T The $\langle Q^2 \rangle$ for direct photons should be smaller than for π^0 s, resulting in a slightly smaller associated yield. This expectation is compatible with the data.

If the contribution from fragmentation photons is not too large $p_{T,\gamma} \approx p_{T,jet}$. The distribution of the quantity x_E defined as $-\vec{p}_{T,trigger} \cdot \vec{p}_{T,associated}/|p_{T,trigger}|^2$ may then be taken as a good proxy for the fragmentation function of the away-side jet and should therefore approximately scale with p_T . In [2] PHENIX showed that this is not the case for π^0 triggers due the near-side fragmentation. Non-scaling effects such as near-side fragmentation and the k_T effect should be well-understood from $p + p$ data and included in any theoretical description of photon-hadron correlations. In nuclear collisions this would allow energy loss effects to be understood quantitatively and unambiguously.

Figure 3 shows x_E distributions for direct photon triggers from the Run 5 $p + p$ data. The p_T range of the charged hadrons is $1 - 5 \text{ GeV}$. The x_E distributions were fit to an exponential in the range $1.0/p_{T,trigger} < x_E < 5.0/p_{T,trigger}$. The slope parameter of the x_E distributions are shown along with fits to the Run 3 and Run 5 π^0 data in figure 4. The x_E distributions for direct photon triggers are larger than that of π^0 triggers and to be rising with p_T within large uncertainties. The increased statistics available from the Run 6 data set will better determine whether the direct photon x_E distributions scale with p_T .

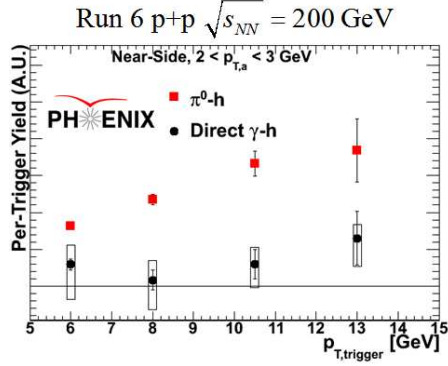


Figure 1. Near-side per-trigger yield of charged hadrons vs trigger p_T for π^0 triggers (■) and direct photon triggers (●).

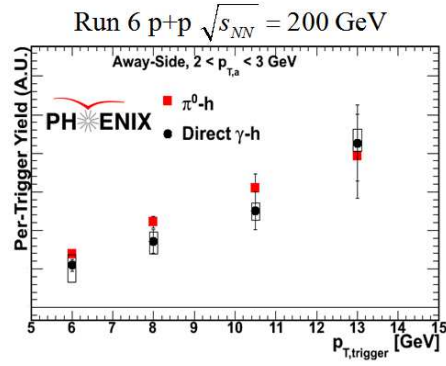


Figure 2. Away-side per-trigger yield of charged hadrons vs trigger p_T for π^0 triggers (■) and direct photon triggers (●).

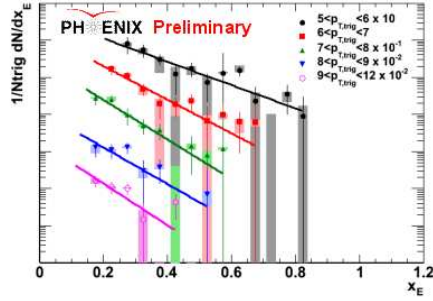


Figure 3. x_E distributions of direct photon-hadron pairs. Different $p_{T,\gamma}$ selections are offset by factors of 10 for clarity. The p_T range for charged hadrons is 1-5 GeV.

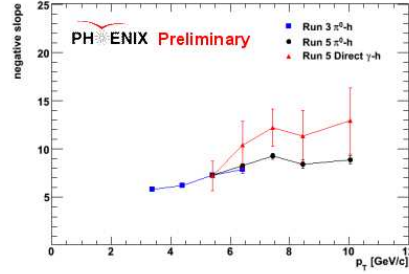


Figure 4. Slope parameter of exponential fits to x_E distributions for π^0 and direct photon triggers.

Figure 5 shows per-trigger yields as a function of $\Delta\phi$ for photons between 7 and 9 GeV and several different partner p_T bins in central $Au + Au$ (0-20%). Inclusive (●), decay (■) and direct photon (▲) yields are shown. The sizeable errors on the direct photon associated yields correspond to additional uncertainties in the under-lying event, elliptic flow subtraction which are not present in the p+p analysis. The systematic errors associated with the ZYAM normalization procedure are shown separately for the inclusive and decay yields. The ZYAM procedure is described in [8].

The near-side yields for direct photon triggers are small enough to rule out a large contribution from fragmentation. The away-side yields are already noticeably suppressed in the inclusive sample and the suppression in the direct photon sample is comparable or greater than for inclusive triggers.

The fragmentation component of the direct photon signal should be measured as a background to the prompt photon component but may also prove to be an interesting energy loss observable itself. [9] By triggering on high p_T charged hadrons and looking at the correlated direct photon production within one radian of ϕ (\sim the typical near-side jet width) the fragmentation yield

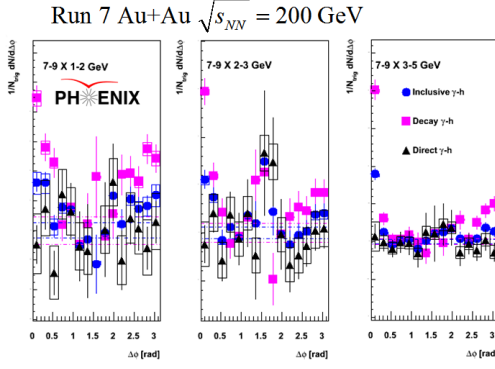


Figure 5. Per-trigger yields of charged hadrons for inclusive (\bullet), decay (\blacksquare) and direct photon (\blacktriangle) triggers vs. $\Delta\phi$ in central $Au + Au$ collisions.

can be analyzed directly. To achieve this, the conditional yield of inclusive photons, π^0 's and η 's are measured where the π^0 and η are tagged by their invariant mass. The decay yield can be estimated from the measured π^0 and η by evaluating the tagging efficiency via a detailed Monte Carlo simulation. By subtracting the decay contribution from the inclusive sample one should be left solely with hadron-fragmentation photon pairs since the prompt photons should seldom be associated with charged hadrons on the near side. Figure 6 shows the per-trigger yield for charged hadrons in the p_T range 2 – 5 GeV with inclusive (\diamond) and direct (\circ) photons. Figure 7 shows the ratio of the per-trigger yields of hadron-direct photon pairs to hadron-inclusive photon pairs as a function of photon p_T . The uncertainties in the measurement are smallest for photons between 3 and 7 GeV. The fraction of hadron-photon pairs coming from fragmentation in that region is constrained to be between 5-15 % after the uncertainties are taken into account. More work will be done to relate this two particle measurement to predictions for the rate of single fragmentation photons.

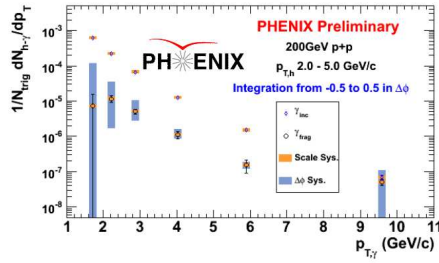


Figure 6. Per-trigger yields of associated inclusive (\diamond) and direct (\circ) photons as a function of p_T .

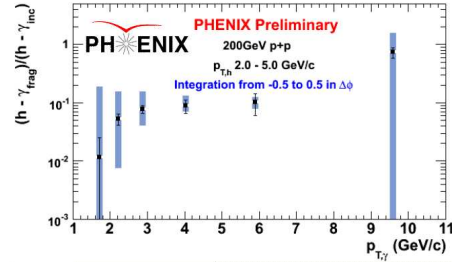


Figure 7. The ratio of the yield of associated direct photons to associated inclusive photons as a function of photon p_T .

3. Conclusions

Direct Photon-Hadron correlations have been measured in $p + p$ and $Au + Au$ collisions using a statistical subtraction method. Neither data set shows a large near-side associated yield suggesting that prompt photons dominate the direct photon sample. For $p + p$ the away-side yield associated with direct photons is similar to the π^0 associated yield within errors. For $Au + Au$ collisions the away-side yield is significantly suppressed. x_E distributions have been measured from the $p + p$ data, but at present the uncertainties are too large to test whether the

x_E distribution scales with p_T . Hadron-Photon correlation measurements have been performed which measure the yield of hadron-fragmentation photon pairs directly. For photons in the range 3-7 GeV the fraction of hadron-photon pairs that come from fragmentation within 0.5 radians in azimuth is between 5-15 %.

References

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